Scalable Interfaces for Mounted and Dismounted Unmanned Systems Control

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ABSTRACT

The next generation Soldier will be required to provide control for both ground and air unmanned systems in support of future combat operations. Unmanned systems show a great deal of promise in that they will increase Soldier safety and enhance situational awareness, but based on their current state of autonomy, will require high levels of interaction from the operator. These interactions will range from platform and payload control while mounted within a combat vehicle to dismounted outside or some distance away from the vehicle, and will be performed in addition to his or her primary mission. In order to effectively work together with these systems, he or she must have a consistent interface that provides intuitive control of primary unmanned system functions and does not impose a unique training burden. In addition, the interface must be able to present information to the Soldier independent of display size and environmental conditions, minimize power and weight, and provide the proper control devices necessary to manipulate vehicle functions to include mobility, sensors and weapons.

Keywords: HRI, interaction, Soldier-machine, robot, unmanned systems, scalable interface, displays, control

1. INTRODUCTION

The Technologies for Human-Robot Interactions (HRI) in Soldier-Robot Teaming Army Technology Objective (ATO) was established in 2004 as a joint program between the Tank-Automotive Research, Development and Engineering Center (TARDEC) and the Army Research Laboratory's (ARL) Human Research and Engineering Directorate (HRED), both agencies under the Army Materiel Command's (AMC) Research, Development and Engineering Command (RDECOM). As of Fiscal Year 2006, HRI has been combined with RDECOM's Aviation and Missile Research, Development and Engineering Center's (AMRDEC) Unmanned Autonomous Collaborative Operations (UACO) ATO to become the Robotics Collaborations ATO (Fig 1).

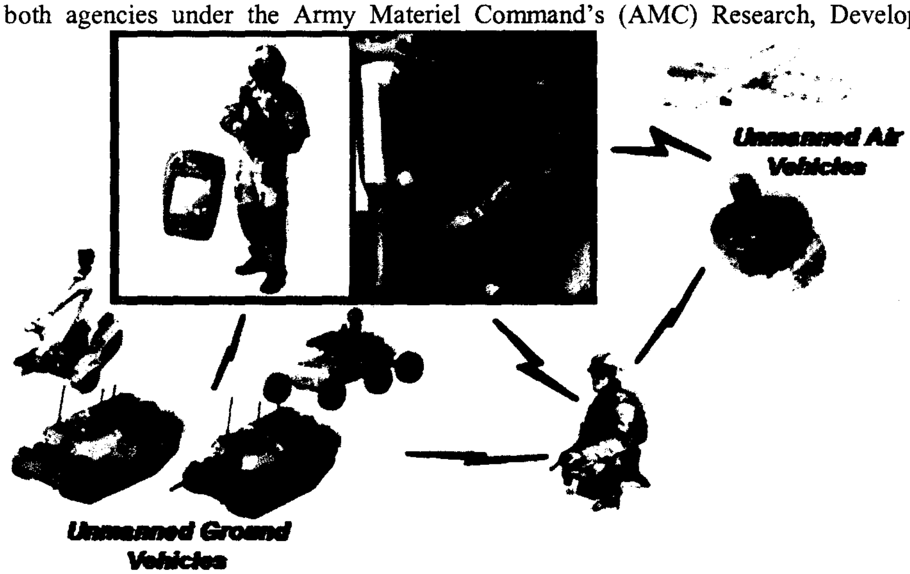

Figure 1: Robotics Collaboration Army Technology Objective (ATO)

The HRI Program came into being as a direct result of an Army Science Board Study[1] conducted in 2002 that assessed research and development efforts focused on human-machine interfaces and command and control of robots and found an absence of a

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15. SUBJECT TERMS
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systematic study of human-robot interface design exists as well as a disconnect between end-users and the development process. Further, they recommended the establishment of a Science and Technology program aimed at developing a technical architecture for human-robot interactions focused on ground robots...the HRI Program. In addition to the development of a technical architecture, this program's objective is to provide intelligent, scalable mounted and dismounted control of ground and air unmanned systems. This is accomplished through the maturation of six key pacing technologies and concepts: extensive task decomposition and analysis to establish the workload of the Soldier; intelligent agent development for offloading or automating Soldier tasks for optimum workload; scalable interfaces for presenting all relevant information to the mounted and dismounted Soldier regardless of his equipment configuration and mission; recursive modeling to refine and validate models developed throughout the program; exploration of teaming concepts to optimize how human and robot teams collaborate to perform a mission, including safe operations of unmanned systems amongst humans and improving local security and situational awareness around the vehicle due to limit or constrained sensor views.

With the addition of AMRDEC's UACO Program, this ATO has enlarged to accommodate collaborative behaviors between unmanned air systems, which further reduces the workload on the Soldier. This paper, however, will focus primarily on the Human-Robot Interactions portion of this Army Technology Objective.

The intent of this paper is to provide background information on the HRI Program, highlight the focus of its use within the Army's Future Force, explain concepts of scalability for extending unmanned system's control from mounted to dismounted operations, and provide an overview of technologies under investigation for use in this program.

Section two of this paper provides details of the intended application of the technology developed under the HRI Program. Specifically, it address platoon and lower operations of the future force where utilization of unmanned systems is identified, and does not cover special applications of robot use. Products from this program primarily feed Future Combat Systems' concepts of operations.

Section three outlines the approach the HRI Program will utilize, to include architecture, automations and presentation, to address scaling functions across varying display sizes and missions. Questions such as how is the same look and feel for the execution of a task maintained, especially with less display space for dismounted operations and how does the Soldier still perform his/her primary tasks with the added responsibility of unmanned systems control are addressed.

Section four provides an assessment of current technologies under investigation for incorporation or leveraging within the HRI Program. Primarily display technologies are explored, as well as inceptor devices for interacting with the systems under control.

Section five of this paper concludes with future plans for the program, and identifies areas of opportunity in the field of human-robot interactions.

2. APPLICATION FOCUS FOR HRI

The U.S. Army is in the process of a major transformation; it is becoming more agile and modular in structure, which will permit it to see first, understand first, decide and act first, finish decisively, and survive and endure. This capabilities-based Force will be more responsive, faster, have extended reach and increased effectiveness. In addition, this highly flexible, networked force will be able to rapidly deploy and task organize to deal with contingencies in joint warfare and conflict resolution. The Future Combat Systems force structure is shown below (Fig 2), and supports operations in the 2010 timeframe and beyond. Part of this force structure change includes the organic employment of unmanned systems, which will increase both the standoff distance and time, keep Soldiers out of harm's way, and provide increased situational awareness to the Soldier...extending the capability of military operations. The majority of robotic control will be conducted at the squad through company level, with the exception of Class III and Class IV Unmanned Aerial Vehicles (UAV's), which are deployed at the battalion and brigade echelon's, respectively. The HRI Program will focus on platoon and below operations and the Manned Ground Vehicle (MGV) variants that provide unmanned systems control. The appropriate vehicles are highlighted in red in Figure 2, and primarily consist of the following MGV variants: Command and Control Vehicle (C2V), the Reconnaissance and Surveillance Vehicle

(R&SV), Mounted Combat System (MCS) and Infantry Carrier Vehicle (ICV). The unmanned systems focus is on the Armed Robotics Vehicle (ARV, all variations), the Multifunction Utility/Logistics Equipment (MULE, all variations), Unattended Ground Sensors (UGS) and Class I and II UAV's. Figure 3 depicts the vehicle systems of FCS, with the manned systems on the left, the unmanned systems on the right and the Soldier/Network in the middle, tying the systems together.

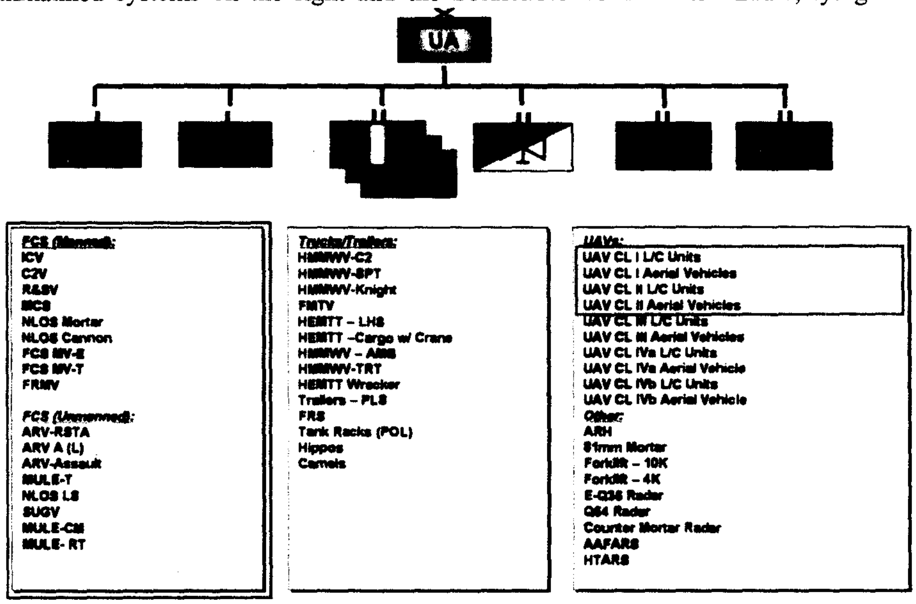

Figure 2: Future Combat Systems Unit of Action

The HRI Program will focus on how mounted and dismounted Soldiers team with unmanned systems to effectively execute a mission. While the concept of teaming logically extends to Soldier-Soldier interactions (more mature) and Robot-Robot interactions (future capability), focusing first on how the Soldier interacts with the Robot will provide a baseline capability that can be easily extended to these other problem sets. Other Army programs are addressing Robot-Robot collaboration, in particular, AMRDEC's UACO Program is exploring UAV platform-based collaborative behaviors and autonomy that will make UAV's more capable and reduce the controlling burden on the Soldier. Also, under the Near-Autonomous Unmanned Systems ATO, TARDEC's ARV Robotic Technologies Program is developing tactical behaviors for ARV platforms that will provide these unmanned systems with autonomous capability, as well as exploring vehicle self-defense to include human intent analysis, and integration of advanced perception capabilities to provide the Soldier with enhanced situational awareness. Together, these Army programs are advancing the state of the art for robotic-related technologies.

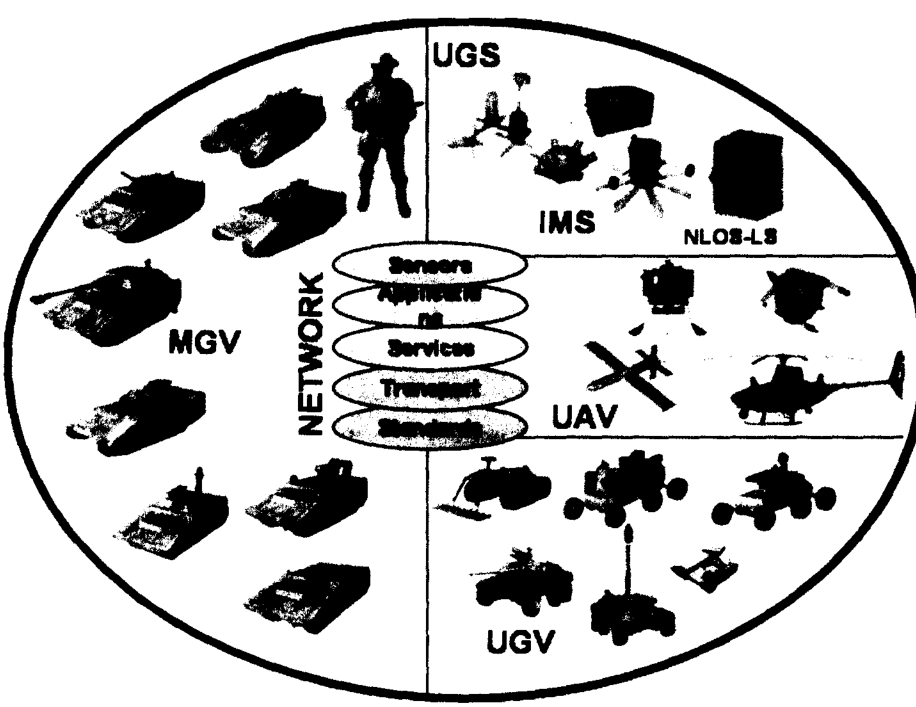

Figure 3: FCS Vehicle Systems

The next section explains the methodology the HRI Program will employ to tackle the issues of portability and distributed knowledge through architecture, Soldier task automation to reduce workload and increase situational awareness, and scalability of the interface to provide a constant look and feel for like tasks across varying hardware configurations. A control architecture provides the framework for implementation of services and data sharing, enabling easy integration and plug and play capability of mature software and hardware products. On this baseline technique, termed presentation description document (PDD), has been identified that provides for the specification of the FCS WMI in separable meta format files which can be assimilated and executed at run time. The HRI Program has defined a similar approach with respect to meta graphical interface description; however, the HRI Program is additionally addressing WMI scalability and adaptability and as such, has incorporated metadata above and beyond that currently under development within the FCS program. As with the service based approach; however, the intent is to provide a WMI description technique that can be readily correlated to the FCS PDD and to eventually provide the ability to convert PDD's to HRI scalable interface description and vice-versa.

To enable a more direct association with the FCS program, the HRI Program is employing the FCS System of Systems Common Operating Environment (SOSCOE) as a middleware service layer, which will be leveraged primarily for its communication (discovery and dissemination), repository (data store), configuration and control, interoperability, and task integration network services. This will facilitate components designed within the HRI Program, although implemented differently, to be correlated to and in some cases interfaced with FCS manned ground vehicle and common crew workstations, dismounted warrior and control device systems, and system of systems integration laboratory assets.

3.1.2. Scalable Interface

Central to the control and interaction with unmanned systems, is the WMI. Within the HRI Program, the WMI provides for all interactions with the unmanned system and is not bounded by today's control concepts, typically implemented via graphical user interfaces packaged into operator control units. Driven by the necessity to advance operator effectiveness in multi-tasking environments, the HRI Program is researching and analyzing various unmanned system control and interaction techniques to include haptic, tactile, 3D audio, and speech recognition. Given these focus areas, the WMI must be flexible enough to accommodate technology insertion and non-traditional input/output techniques along a non-linear traditional GUI continuum. An example might be controlling a robot via joystick (tele-op) on one end of the continuum, while controlling a robot via hand gestures and/or speech at the other extreme. To facilitate technology analysis and experimentation along this continuum, the HRI Program is developing a scalable architecture with the high level goals of supporting commonality, scalability, portability, and adaptability.

In order to further describe the techniques employed within the scalable interface approach, it is important to differentiate scalability as defined by the HRI Program from the traditional interpretation of shrinking or stretching a graphical interface as the WMI is ported among displays of varying size. For HRI, scalability is a farther reaching concept, addressing WMI scalability that includes graphical stretching/shrinking, but additionally takes into account configuration, alternate graphical representation, role-based representation, and prioritization of interface information.

The concept presented in Figure 6 below depicts the specification approach to support HRI scalability. The WMI description is encapsulated in four files. These are the interface description, which defines the graphical user interface layout in a non-device/graphics independent manner; the destination hardware description, which defines the target hardware environment to which the WMI will be deployed; the user preferences, which defines the style for the resultant rendering of the graphical objects; and finally HFE guidelines, which provides human factors information and rules that will be combined with the style and interface to deploy the WMI to the specified target display The scalable interface description information is processed by the scaling engine, which in turn generates a widget display list. The widget display list is processed by a conceptual presenter and rendered/translated to the target system. In some cases, the target system could simply be a display. Alternately, the target system could be the combination of a display with a speech recognition system, or an HMD with a tactile control/feedback system. The intended goal scalable interface for the HRI Program is to be able to represent one interface description on any of these combinations. Within the HRI Program these scalable interface descriptions will be utilized to specify and interchange human-robotic information between robotic vehicles and controllers, supporting discovery and reconfiguration of robotic systems.

As described in section 2, the FCS program provides for the control of robotic assets via its manned ground vehicle systems. This control is implemented via a set of battle command services interfaced through operator workstations and MGV common crewstations. Control of FCS unmanned assets from the dismounted operator is provided through dismounted control and Soldier-borne devices. Battle command services are coordinated through task integration networks (TIN's) which can be interfaced to the operator via the Warfighter-Machine Interface (WMI). The WMI, in turn, is described via presentation description documents (PDD) that are processed, displayed to, and interacted with by the crewstation operator. Currently UAV's are targeted for integration within FCS spin out 2; to be fielded in FY12, while UGV's are targeted for integration within FCS spin out 3; to be fielded FY14 (See Figure 5).

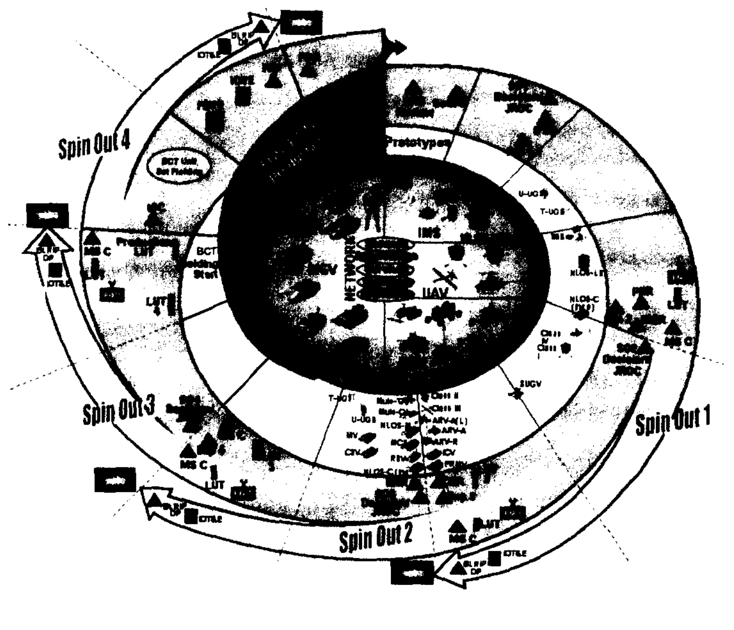

Figure 5: FCS Spin Out Architecture

At this point in time, the FCS manned and unmanned vehicle architectures, WMI, and battle command services are still evolving and will be made available through a coordinated build plan approach supporting the development of spin out 2 and spin out 3 infrastructure and services.

Given that the HRI products and experimental data in their final form are focused towards transition to and application within the FCS program, an architectural approach, further described in the following subsection, has been defined that provides a parallel to the FCS architecture with respect to WMI, agent insertion, and task network integration to more easily allow for transition throughout the FCS program SDD and spin out increment phases.

3.1.1. Architecture

While the task of human/robotic interface analysis is focused primarily on the manner in which the human operator interacts to control and monitor one or more robotic assets, it is important to remember that this interaction reaches far beyond traditional operator control units, displays, and input devices. Essential to the analysis is the integration of automation and agents to assist the operator in control and monitoring (integrated within both the manned and unmanned platforms) as is also the data model that enables agents, operators, and WMI's to interface with robotic entities.

For the HRI Program, it was desirable to develop an approach that would allow not only the advancement of research in key program areas, but at the same time provide synergy and data transition with the FCS program. However, the HRI Program was at a bit of a disadvantage towards meeting this specific objective, given that the development of WMI and Crewstation components for the FCS program are still in requirements and early design phases. To overcome this obstacle, the HRI Program analyzed relevant FCS program areas (common crewstation, dismounted control devices, battle command, and WMI services) and evolved an approach that would provide for correlation among FCS and HRI technologies/components. The approach centered around two main elements. The first of these elements was the specification of a service based architecture approach, providing for the discovery of and interaction with services, agents, and automations. Analysis and task decomposition conducted within the analysis phase of the HRI Program will be utilized to derive the services as well as the interconnecting logical data model. The resultant task networks, services, and data model will be developed in a manner that facilitates correlation to FCS battle command services. The second element was the definition of an WMI specification technique. Within the FCS program a specification capability, task automations that reduce workload when the Soldier is overloaded or stressed can first be identified, then developed and readily integrated into the system, then simulated to explore the overall increase in performance. These automations are complimented by smart Soldier-Machine Interface (SMI) configurations and layouts that make the system easier to use. Lastly, scaling tasks so that the same functionality can be represented on varying hardware configurations is explored. The main point here is that as display space is lost when going from a mounted mission with multiple large displays down to perhaps a wearable display when performing dismounted operations, how are tasks performed through a combination of visual representation and alternative devices that make up for lost display real estate.

3. PROGRAM METHODOLOGY

TARDEC and ARL-HRED are teaming to solve human-robot interactions for mounted and dismounted control of ground and air unmanned systems. An end-to-end systems engineering approach has been employed to solve this problem; starting with the identification of soldier requirements for conducting missions while teaming with unmanned assets. Requirements are decomposed from system level behaviors through the identification of operator roles and tasks required to implement those roles within specific use cases or operational contexts (i.e., mission threads). Identified tasks are further decomposed into task networks captured via an intelligent systems ontology that defines both control and data flow within the networks. To the extent possible, task networks are derived independent of specific technology or allocation (e.g., hardware, architecture, or human operators). As behaviors are derived and captured, modeling and analysis is conducted through the mapping of task networks to roles, which are then deployed to system level components capable of executing the defined roles. These deployments are then constructively simulated utilizing an intelligent systems behavior simulator (depicted below in Figure 4).

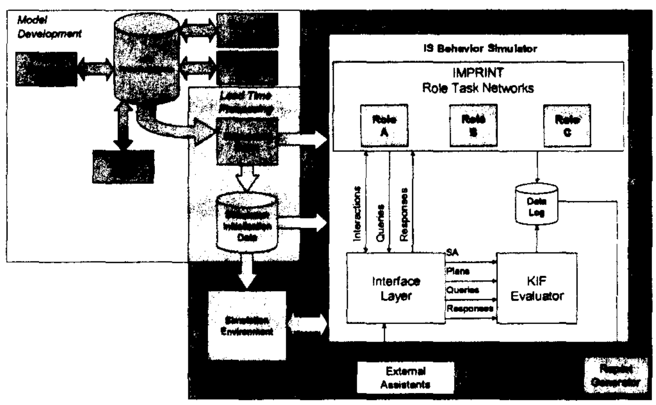

Figure 4: ISBS Behavior Simulator

As represented in the figure, the behavior simulator executes task networks that have been specified and captured within the knowledgebase during model development and translated into executable form during load time processing. Intermediate data produced in the load time processing will be generated (as required by the models) to support model interfacing to external agents and simulation/stimulation environments. These interactions dynamically stimulate the task networks during run time, which in turn provides the capability to measure the effectiveness/performance of the deployment for a specific use case or environmental scenario. In general, the HRI Program is focused on the variation of deployment technologies (displays, input devices/techniques, and agents) within this phase of the program to isolate viable candidates for system integration and field test. The primary metrics utilized within this phase of the analysis are operator workload and effectiveness with respect to human/robotic task allocation.

3.1. Program Components

For validation and experimentation purposes, candidate HRI technologies identified within the analysis phase of the program will be further developed and integrated into mounted and dismounted configurations and tested within crewstation and Soldier testbeds in the HRI system integration laboratory (SIL). Maturation and validation of these technologies within the SIL environment will in turn lead to refinement and eventual system field test and experimentation, supporting future force operations and the FCS program.

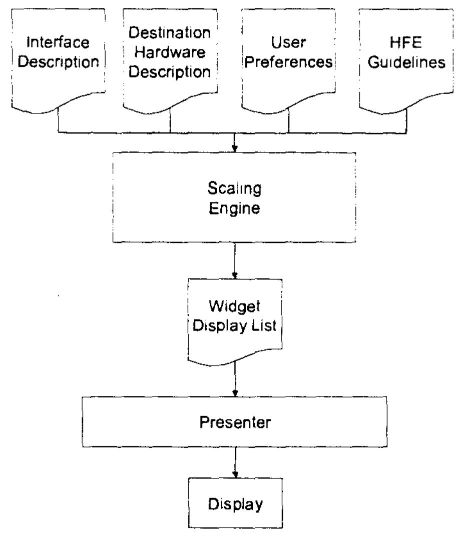

Figure 6: Scalable Interface Description Approach

3.1.3. WMI Guidelines

An essential component supporting the standardization of common WMI is the establishment of a set of guidelines governing WMI methodology and principles within the relevant domain. The HRI Program is analyzing requirements in order to establish a consistent set of guidelines that can be interpreted within an interface to support common look, feel, and scalability. In some instances, these guidelines will be incorporated into the HFE metadata encoding and will address the following areas of scalable interface design: configurability, display layout, data logging, operator login, status, and modes of operation. Configurability addresses dynamic reconfigurability of controller and robot interfaces providing the ability to upload platform configuration specific data for display. Platform specific data could include mission package configuration, mission package controls and status, as well as robotic platform specific controls and status. Display layout addresses the manner in which a screen can be physically and/or virtually addressed supporting the placement of controls and status indicators. General terms and methods applicable across interfaces would be defined in an abstract manner such that they could be mapped accordingly within a physical interface design, for example warning, caution, and alert (WCA) levels and help. To the degree applicable, static display areas will be defined for the display of critical data such as status and WCA's. Data logging addresses the type of data that may be logged for training, validation, and/or analysis purposes. Logged data could include WCA, audio, images, and session data. Operator login addresses the manner in which an operator gains access to the WMI, systems controlled by the interface, and the role access of the operator within a session. Status addresses the manner in which operator critical status information is defined and accessed. Critical status information could include robotic vehicle status, mission status, vehicle orientation, communication link status, and battery levels. Modes of operation address controller modes of operation and the interface behavior within each respective mode. Example modes could include setup (configuration, diagnostics, log/other status), pre/post operational (mission planning and mission analysis), operational (tactical operations), sleep (reserve), and training (embedded training, mission playback and analysis).

4. HARDWARE

In general, controls and displays used by the military can be put into three broad categories: large single or multi-screen crew station configurations typically used in manned ground vehicles; portable single-screen environmentally protected suitcase-sized devices for use in a host of environments or COTS workstations for Tactical Operations Center (TOC) type operations; and small highly portable and light weight devices to be used by the dismounted Soldier.

4.1. Crew Stations

Crew stations offer the most display space and versatility for control of manned and unmanned vehicle assets. Because it is vehicle based and nothing is carried by the Soldier, the crew station has a greater quantity of display and control space maximizing information display and system control. Typically currently fielded vehicle crew stations will have at least one and usually more displays dedicated to a specific vehicle function such as target acquisition or map services. Likewise, controls are dedicated hard buttons, switches, dials, etc. for control of specific vehicle functions. The picture on the left in Figure 7 shows the gunner's station of a Stryker vehicle as an example of this. Display screens tend to be active matrix or thin film transistor based LCD screens because of the good image quality for displaying map data, wide color range, and thin form factor saving interior vehicle space.

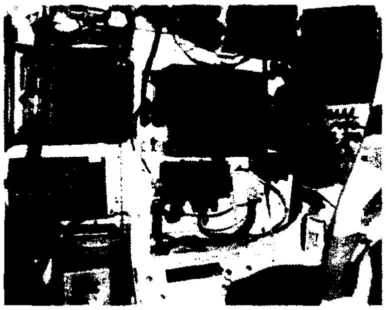
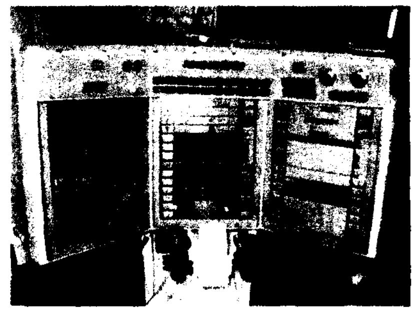

Figure 7: Stryker crewstation (left) & Prototype TARDEC crewstation (right)

Future designs will enlarge displays and add soft reconfigurable controls minimizing the amount of subsystem unique dedicated controls and increasing screen size for maximum information display. Figure 7 shows a functional crew station prototype that can be used in the performance of multiple mission types and for control of unmanned ground and air vehicles. Notice how the amount of display space has increased tremendously over what is currently fielded in the Stryker vehicles. It's envisioned that a crew station similar to the one on the right in Figure 7 can be used in all the FCS manned ground vehicle variants regardless of mission type. The larger display space accommodates driving functions, command and control, weapons control, and communications all from the same station. This same crew station can be used in each FCS vehicle variant eliminating unique hardware and reducing training requirements across vehicle variants due to unique hardware. Add to this an SMI with a common look, feel, and function, across all the vehicle variants, and the training burden is even further reduced. Because more information can be displayed to the Soldier either continuously or on demand, task performance can be increased as ease of information accessibility and system control has been increased. Add to this configuration alternative control and display capabilities such as 3D-audio, speech recognition, touch panels, etc, and Soldier task performance increases even further as he/she can now perform tasks in parallel and have greater situational awareness than before. An additional advantage also lays in future growth. As vehicles age and new enhancement packages are added, the user interface can be changed completely in software with no physical modifications needed to the vehicle crew stations which can be a tremendous cost savings.

4.2. Workstations and Portable Computers

Another common configuration of control/display device used by the Army is the workstation, rugged laptop or suitcase style computer. Typically used for command and control activities at the platoon level and TOC, or for control of unmanned systems from a command vehicle, fixed location or sometimes even on foot. These are usually single screen LCD devices (like those shown in Figure 8) that provide command and control, communications, and video or information feedback from unmanned systems. Most every UGV, UAV, or UGS has a unique proprietary control and display device developed by the manufacturer. As a result, scores of different workstation and portable computers find their way in theater making supportability increasing difficult because of the number of systems that must be maintained, repaired, or replaced. But as the Army moves forward with the FCS program and concepts for

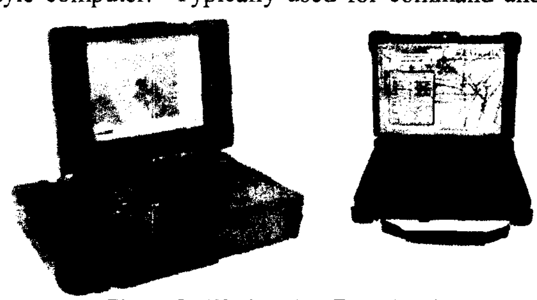

Figure 8: Workstation Type Displays

controls and displays are matured, multiple unmanned systems will be controlled from many fewer devices.

4.3. Small Soldier Portable Devices

The FCS vision is for the dismounted Soldier to also have full control of unmanned systems on par with that of the mounted controller. However, the dismounted Soldier can't afford to be burdened with cumbersome and heavy equipment as they lack the room to pack the devices, and any additional weight becomes an extreme physical burden. Therefore, the dismounted Soldier needs to be equipped with much smaller devices similar to those shown in Figure 9.

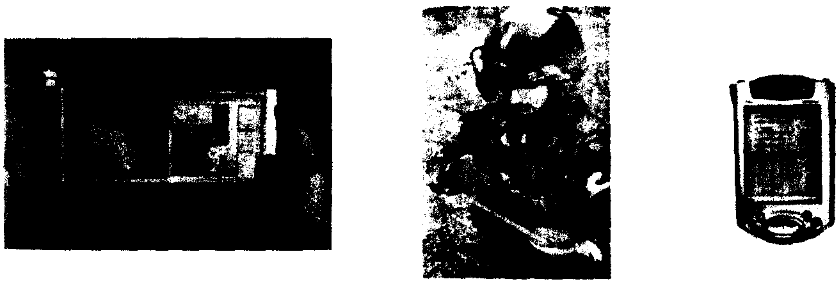

Figure 9: Portable Display Devices

Shown here are a flexible display, tablet display, and a PDA style device. The preferred device ultimately will be the flexible display as it offers all the features of the standard LCD display but in an extremely thin and lightweight form factor that can even be integrated into a Soldier's uniform nearly eliminating all Soldier portable space claims except for the power source. The Army estimates that the first flexible displays will be ready for introduction to the dismounted Soldier in FY08. The tablet device offers significantly more screen space but at the cost of added weight and space. The PDA is the opposite, very lightweight and compact but with little screen space.

Another type of device that may be worn by the dismounted Soldier is the Helmet/Head Mounted Display or HMD. The HMD is usually a monocular or sometimes a binocular device involving the projections of graphical images, or overlays onto glass, a mirror, or directly into a small LCD that the Soldier can view. The glass option has transparent properties making it possible for the Soldier to still see his environment while viewing images or overlays without having to look away from his point of interest.

4.4. Criteria for Display Systems

Whether large or small, there are criteria necessary for all displays to have to meet for use in military environments. These include:

- High brightness/high contrast for reading in direct sunlight
- Operable in extreme temperature ranges for operation in all world regions
- Must be resistant to vibration and shock loads in excess of 20g
- Waterproof or water resistant for operation in all weather conditions
- Low EMI emissions for low visibility to detection devices

These are basic elements that are called out in most MIL-STD's or industry standards related to displays. However, advancements in technology such as gaming systems are driving the hardware in ways that the military hasn't necessarily considered in the past and may become future criteria for all displays:

- 3D acceleration for in-vehicle training, mission rehearsal, and battlefield visualization.
- Video rendering for streaming video from unmanned assets.
- Touch panels (resistive, capacitive, IR, or SAW) for alternate input methods.

3D acceleration and video rendering capabilities for Army applications require more powerful video cards than ever before. Large, high resolution graphical databases for performing in-vehicle embedded training, mission rehearsal, and battlefield visualization will require cards that can render multiple channels of graphics with even more polygons than today's fastest gaming based PC's. Likewise multiple channels of high resolution video that can be manipulated in real-time (rotated and resized to fit where needed in the display space) will require extreme processing. Fortunately, the gaming industry is constantly moving in this direction pushing the state of the art. PC's now utilize multiple graphics cards with support for large polygonal models and terrain. Commercial PC form factors such as PCI express are being produced in rugged versions for military applications.

4.5. Tactile Displays

Tactile displays may be a useful cueing system for future military operations. Tactile displays make use of vibration or pressure based stimulators placed on or near the skin. Multiple stimulators placed at varying locations on the body can enhance situational awareness by indicating the direction of an item of interest. Even more information can be obtained when varying frequency or intensity of the pressure or vibration stimulator. IMPRINT modeling and simulation performed at a variety of Army and university labs have indicated that when combined with visual and auditory cueing systems tactile displays can have a positive affect on situational awareness and decision making for the mounted platoon leader[2]. Typically, haptic/tactile displays for military usage take the form of a vest (Figure 10) worn by the Soldier. The vest has vibro-tactile stimulators, pressure-tactile stimulators, or a mix of both embedded into it at varying degrees relative to some reference point on the torso, that can be individually activated to draw the wearer's attention to a location or item of interest. They can be used to for such things as warnings and alerts, provide assistance with navigation and guidance, system locations within a vehicle, or even indicate threat warnings external to the vehicle.

Figure 10: Tactile Vest

4.6. 3D-Audio Displays

3D-audio display systems have great potential for assisting the Soldier with situational awareness and task performance. 3D-audio systems spatially organize sound, making it seem as though it's coming from behind or from the side, allowing the listener to more easily process information. This is sometimes known as the "cocktail party" effect. If five people are speaking at the same time, it's easier to focus on what one of them is saying when they are spaced out from each other. This effect is achieved through software processing of head related transfer functions or HRTF's. The HRTF takes into consideration the physical properties of the outer and inner ear, and the time differences associated with sound pressure waves reaching the left and right ear. A sound source coming from the left will reach the left ear before the right ear by a fraction of a second. This perceived time separation is one of the things that makes a sound source actually sound like it's coming from a specific direction. Elaborate HRTF's may also take into account sound source volume based on distance from the listener, sound wave reflections in the listening space, and how sound propagates through not only the ears but the head and torso as well. This benefits the Soldier by making it easier to hear voice traffic over the intercom or radio system. It can also be used to draw the Soldier's attention to a location or item of interest inside or outside of the vehicle, and be used for warnings and alerts, or as navigation assistance.

3D-audio works best when heard through head-phones where extraneous environmental sounds are muffled out or eliminated. Audio processors are needed to apply the HRTF to an incoming audio stream in order to "spacialize" it as normal audio such as that over an intercom has no three dimensional properties other than perhaps stereo. This audio processing hardware and the HRTF's used to be costly to implement, but with the advent of 3D-audio capabilities in video/virtual world gaming, basic 3D-audio capabilities have become much more economic. One additional piece of hardware potentially required for 3D-audio depending on the intended application is a head tracker. A head tracker monitors the orientation of the listeners head. When taking this into account, 3D-audio systems can make a sound appear to emanate from a fixed location in space, say to the north, regardless of which way the listener's head is oriented. Without this, the sound will move with the listener's head as he/she turns it.

4.7. Interface Scalability and Display Deconfliction

Given the various current and future control and display systems as described above, the notion of scalability becomes very important. How do you efficiently represent information and provide dynamic control of manned and unmanned systems when moving from a large display space such as a crew station to a smaller display space such as a PDA with no degradation in mission performance? It's clear that all control and display mechanisms on the larger display physically will not fit on the smaller display. Given this, why not display to the Soldier at the top level, the information or control elements most crucial to his mission performance or those needing access most frequently. Items of secondary importance or not accessed as frequently can be buried down into lower levels or layers of the interface. Also, where possible automate actions that don't necessarily need close Soldier monitoring. For example it might be beneficial to have a robot navigate autonomously instead of being tele-operated by the Soldier so that he can use his limited display space for viewing recon sensor information. Automations can be turned on and off as needed depending on the circumstances. The whole process itself can be automated through the use of intelligent agents. The agents are aware of display size limitations, the level of automation available on platforms, and what is important to show to the Soldier at any given time for his mission type. The agents can then intelligently decide what to automate and when, and what to show to the Soldier and in what format and dynamically make changes before during or after a mission adapting to the situation, or they can simply act as a decision aid providing the Soldier with guidance on what to do.

The need for scalability of the Soldier-machine interface becomes even more evident when other types of displays such as tactile and 3D-audio are taken into account. The addition of these display types allows much greater flexibility in how to scale or deconflict elements of the user interface. Take for example the mission of controlling both movement and payloads of two UGV's. From a large multi-screen crew station, finding the display space to place all soft buttons, post alerts and notifications, and receive video and sensor data back from the robots is relatively easy. This is not the case for the same mission with only a single screen workstation as an OCU. Displaying all this information to the Soldier without compromising his/her performance or task overloading him/her may be difficult. The use of these other devices allows for the flexibility to port many of those functions off the visual display and into the audio or haptic space. An alert that an autonomously navigating robot is stuck and needs assistance in tele-operating out of its jam may now be given aurally instead of visually. The location of the robot relative to the Soldier may also be possible through aural or haptic cueing. Many variations on this theme are possible.

Taking this notion one step further, it's possible for displays to modify themselves on the fly, or be adaptive to the operator's needs. If a Soldier is controlling an unmanned asset inside a vehicle from a crew station, and then needs to utilize the Crew Remote Interface System (CRIS) as he/she exits the vehicle, it would be desirable if the system would monitor the state of the crew-station interface, and then automatically configure the smaller display to show the same things being monitored on the larger display with controls and displays now ported across all available devices such as a PDA device, HMD, and tactile vest. Further this notion even one step more. Say a fellow Soldier was incapable of controlling one of his assets and had to hand off control to another Soldier already controlling two small UGV's. In mid-mission his displays could adapt to this change and reconfigure themselves using all available input and display devices to pick-up these extra tasks, but display all needed information in the optimum configuration, perhaps even simultaneously changing the level of automation on the platforms being controlled. This synchronicity between the Soldier, his assets, and his display and control devices is what the HRI Program is starting to address.

5. CONCLUSION

The HRI Program is in the process of tackling a difficult Army problem; providing the Soldier with the proper tools and equipment at varying mission levels to enable mixed initiative operations with unmanned systems. These unmanned systems will ultimately increase the stand off distance with the enemy and expand situational awareness of the battlefield, but currently cause large workload demands on the Soldier and require unique training for each controller solution. These two concerns are the primary focus of the HRI Program. By providing a methodology for normalizing and scaling missions across heterogeneous system interfaces, TARDEC makes a dramatic improvement in reducing training requirements on the Soldier as he/she interacts with different unmanned systems. Additionally, by intuitively laying out the interface in a human-centric fashion and providing automations that perform tasks when the Soldier is overloaded, HRI will help the Soldier realize unparallel levels of performance, better enable him/her to focus on his/her primary mission, and optimize the way Soldier's team with unmanned systems.

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